AFCRL-67-0683

AD 665137

PAST VERSUS PRESENT WIND ACTION IN THE MOJAVE DESERT REGION, CALIFORNIA

by

H. T. U. Smith

Geology Department
University of Massachusetts,
Amherst, Massachusetts

Contract No. AF 19(628) 2486

Project No. 8623

Task No. 862302

Work Unit No. 86230201

Scientific Report No. 1

December, 1967.

Contract Monitor: James T. Neal, Capt., USAF
Terrestrial Sciences Laboratory

Prepared
for
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730

39

AD 665 127

AFCRL-67-0683

PAST VERSUS PRESENT WIND ACTION IN THE MOJAVE DESERT REGION, CALIFORNIA

by

H. T. U. Smith

Geology Department
University of Massachusetts,
Amherst, Massachusetts

Contract No. AF 19(628) 2486

Project No. 8623

Task No. 862302

Work Unit No. 86230201

Scientific Report No. 1

December, 1967.

Contract Monitor: James T. Neal, Capt., USAF
Terrestrial Sciences Laboratory

Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.

Prepared
for
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730

ABSTRACT

At the present time, wind action in the Mojave region is seen in dust devils, sand and dust storms, sand drifting and dune movement, and sandblasting of glass, metal, and wood surfaces. Cumulative effects of wind action are represented by widespread dune fields, sand sheets, deflation basins, and wind-scoured rock surfaces. That the development of those features was followed by an interval of greatly reduced or arrested wind action, however, is indicated by the following phenomena: (1) dissection of eolian sand deposits by gullies and stream channels; (2) presence of stabilized and modified dune surfaces; (3) mantle deposits of coarse detrital material spread out over sloping sand aprons from overtopping ledges; (4) weathering of sandblasted rock surfaces; and (5) discontinuity between eolian effects and sources of sand which must have produced them. These evidences are particularly well displayed, in various combinations, at the southern end of the Sheep Hole Mountains, the Kelso dune area, near the northeastern tip of Cave Mountain, and at the north end of Cronese Mountain. Comparisons with other areas where more adequate criteria are available and have been studied suggest that the major interval of wind action probably was during the Altithermal, between 7500 and 4000 B. P., that this was followed by a relatively less arid interval, with wind action subordinate to other surficial processes, and that modern wind action represents a relatively recent shift in the climatic balance, toward increased aridity. These conclusions have significant implications for the interpretation of playa morphology and stratigraphy, and of other phenomena influenced by climate.

INTRODUCTION

Climatic change serves as the common denominator for a wide range of geologic and geographic phenomena. It conditions the relative effectiveness of various erosional and depositional processes through time, and it provides a basis for comparing and relating effects from one place to another. At particular places, evidence for climatic change inferred from one type of phenomena has implications for the interpretation of other types of phenomena in the same territory. And in carrying studies from better known to lesser known regions, knowledge of climatic effects in the former may contribute to the understanding of otherwise obscure relationships in the latter. This is particularly relevant to photo interpretation of relatively inaccessible areas for which ground data are inadequate. Studies on climatically-induced phenomena thus may have significance far beyond the immediate areas and effects concerned.

Wind action is one geologic process with particular sensitivity to climatic change, and one that is also very common in arid environments. In some regions, relict effects of wind action, such as buried ventifacts and stabilized sand dunes, have long been known and their meaning in terms of climatic chronology appreciated. In the Mojave Desert region, however, the significant effects are less obvious and have passed virtually unnoticed. The vigor of present-day eolian movement of sand and dust seems to have led to the tacit assumption that present conditions are representative of the past back to the time of the major pluvial lakes. With one exception (Sharp, 1966), the literature may be searched in vain for any hint of significant departures from this supposed continuum. Elsewhere in the western U. S., however, it has

been found that climatic fluctuations of significant magnitude have occurred during postglacial time, and that the intensity of wind action was very different at different times (Antevs, 1955; Morrison, 1964; Baumhoff and Heizer, 1965). It would appear unlikely that these effects stopped short of the Mojave region.

In this report, effects of present and of past wind action are differentiated on the basis of criteria which are partly old and partly new, evidence is presented for a past time or times of much reduced wind action, a new variety of geomorphic surface is described, and the implications of these findings for other geomorphic phenomena are considered. The study is based on reconnaissance field investigations started in 1954, and continued during 1963, 1966, and 1967. The presentation begins with a brief commentary on modern wind action, proceeds to a description of the cumulative effects of past eolian activity, and then sets forth the evidence for discontinuity in the development of those effects, based on specific localities.

WIND ACTION AS SEEN TODAY

In the Mojave and surrounding areas, present-day wind action is seen in dust devils, sand and dust storms, and sand drifting. (Clements, 1963). During severe dust storms, visibility may be reduced to 10 feet, and dust rises to heights of hundreds of feet. In sand storms, cars exposed to the wind may have windshields frosted, paint removed, and chrome plating scoured off; as a result of a single storm in Dec. 27, 1953, one insurance company had claims totaling $165,000 for wind damage (Clements, 1963, p. 17). Over an interval of years, wooden telephone poles and fence posts are gradually reduced in cross section near the

ground level (Russel, 1932, p. 103-104), and materials such as brick are measurably eroded where sandblasting is at peak intensity (Sharp, 1964).

Sand drifting by wind action is perhaps less spectacular than the above effects, but is particularly noticeable along highways, where periodic removal of accumulated sand may be required unless protective structures are used. Along abandoned roads, sand drifts may be more conspicuous. On the leeward sides of playas, sand accumulations are common (Blackwelder, 1946). Where dunes occur, their movement over a number of years may amount to hundreds of feet (Long and Sharp, 1964; Norris, 1966), or, where wind direction is more variable, movement in one direction may be more or less cancelled out by that from another (Sharp, 1966). On a smaller scale, effects of wind action are seen in the development and movement of ripples (Sharp, 1963). All in all, the various effects of present-day wind action are indeed noteworthy.

CUMULATIVE EFFECTS OF WIND ACTION.

At many places, the effects of eolian erosion and deposition are of such a nature, or on such a scale, as to indicate long-continued wind action, extending well back into the prehistoric past. Erosional phenomena in this category comprise ventifacts, sand-blasted bedrock surfaces, yardangs, and deflation basins. Danby Dry Lake has been pointed out by Blackwelder (1931) as a type example of the latter, and the gypsum-capped mounds which provided evidence have been mapped also in Cadiz Dry Lake (Kupfer and Bassett, 1962). Deflation in other playas has been referred to by Kupfer and Bassett (1954). Good examples of yardangs have been described by Blackwelder (1934) from the northeast side of Rogers playa, and other examples from the vicinity of Coyote

playa by Hagar (1966); the time required for development of these features is uncertain, but is not necessarily great. Eolian erosion of minor ridge-and-gully topography to leave an almost smooth slope has been noted by Blackwelder (1954), and would appear to require a relatively longer time. Sandblast effects on boulders or bedrock (Blackwelder, 1954; Russell, 1932) may require much or little time, depending on the amount of surface affected, the depth of the grooving or fluting, and the "hardness" of the rock; some deeply fluted crags observed in southern Death Valley must have required a long time for the cutting. In general, however, it appears that large deflation basins, such as Danby, probably represent the greatest amount and longest duration of eolian erosion.

The depositional effects arising from long-continued wind action comprise various types of sand dunes and sand mantles. They are shown on the more recent topographic maps, on some geologic maps (Jennings, 1962; Kupfer and Bassett, 1962), and are referred to in some geologic reports (Thompson, 1929; Clements, et al, 1957; Evans, 1962), but have received comparatively limited detailed study. The most prominent area of dunes in the Mojave in terms of height, extent, and bulk, is known as the Kelso Dunes (Kerens and Flynn topographic sheets), some aspects of which have been studied by Sharp (1966); it is discussed further on later pages of this report. Other lesser areas of eolian sand having distinctive dune form occur at many places, but have relatively low relief; examples are found in the vicinity of Cadiz Dry Lake (Cadiz Lake and Cadiz Valley topographic sheets) and east of Dale Dry Lake (Dale Lake topographic sheet), and other occurrences are mapped by Clements et al (1957), Hager (1966), and Groat (1967). More

widespread are mantle deposits of eolian sand lacking well-defined dune morphology (Smith, 1954). These occur as broad, irregular expanses and drifts along the sides of many desert mountains, from the Mojave into southern Death Valley. Along the higher mountains, the sand laps up on the lower slopes of the windward side. On the lower mountains, however, invasion of sand is relatively more extensive, with tongues, embayments, and ramps reaching up the sides, filling or blocking minor valleys, and in some places passing over the crest to form sand cascades, "glaciers," splays, aprons, or attached sand ridges. Some rock knobs are entirely surrounded by sand, and others undoubtedly are buried beneath it. Examples are found along the Sheep Hole Mountains, Kilbeck Hills, Iron Mountains, Calumet Mountains, and the hills southeast of Soda Lake (Dale Lake, Cadiz Lake, Iron Mountains, Bristol Lake, and Old Dad Mountains topographic sheets, respectively).

EVIDENCE FOR PAST DISCONTINUITY IN WIND ACTION

Indications that wind action was arrested, at least locally, during one or more intervals of past time are found in the following phenomena: (1) dissection of eolian sand aprons by stream channels; (2) occurrence of stabilized and modified dune surfaces; (3) mantling of eolian sand sheets on slopes by coarse detrital material emplaced by gravity; (4) weathering of sand-blasted rock surfaces; and (5) isolation of eolian effects from the sand supply which produced them. These evidences occur in various combinations at different places, and are best discussed on the basis of specific localities, shown in Figure 1.

SHEEP HOLE MOUNTAINS LOCALITY

This locality (A or Fig. 1) lies on the west side of the Sheep Hole Mountains at their southern end, and southeast of Dale Lake (Dale Lake topographic sheet). A sand apron, or climbing dune, laps up against the mountainside for a distance of some 3 miles. The surface slope is from about 4° to 6°, and the sloping area is from about one half mile to one mile in width. At its foot, a dry wash drains toward Dale Dry Lake, and westward from the wash is a dune field of low relief several square miles in extent, and largely semi-stabilized. At the south end the toe of the sand apron is truncated by the dry wash, forming a bluff a few tens of feet in height, and at other places downstream the sand is incised to a lesser degree by the wash. Stream dissection of the sand apron is represented also, more strikingly, by 6 short dry valleys which cross it from the mountain, heading toward or into the main dry wash. The largest of these valleys (Fig. 2A) is 130 feet deep and approximately 270 feet wide near the contact of sand with bedrock, upstream from which it becomes a structural valley trending diagonally part way across the mountain. A small outlier of sand occurs along the side of this valley about one quarter of a mile from the main mass of sand, indicating that the bedrock valley formerly was filled with sand to at least that point. The other valleys are smaller, decrease in size downstream, and receive their flow from more limited areas in the bedrock. All tend, in their upper reaches, either to follow the contact of sand with bedrock or to send out tributaries which do; as a result the contact zone is considerably dissected and stretches where the sand apron merges into the mountainside without interruption are minor. However, where the contact is dissected, projection of the surface slope of the sand

apron to the mountain front commonly meets a line of demarcation between lighter rock below and darker rock above (Fig. 2B). On examination, this contrast is found to represent a difference in the proportion of rock surface covered by desert varnish. In the lower, lighter, zone, the desert varnish is more patchy, and it appears that a once more extensive varnished surface has been reduced by granular disintegration of the rock. It is inferred that, prior to dissection, the sand cover extended up to the line of color change, and it is suggested that retention of moisture by the sand may have promoted the process of disintegration. The importance of moisture in this connection has been noted by Barton (1916) and Blackwelder (1954), and enters into Wahrhaftig's (1965) hypothesis for the origin of stepped topography in the Sierra Nevada.

On the gently-sloping upper surface of the sand apron between dissecting valleys, there is an irregular and discontinuous scattering of angular rock fragments - a sort of crude, incipient desert pavement. These appear to have been washed down from the rocky slopes above, prior to dissection. Scattered desert shrubs also dot the surface. In general, the sand appears to be essentially stable, with no influx of new material by wind. Locally, however, there are small, irregular patches of actively-drifting sand, conspicuous by its lighter color. Present sand drifting is too limited and too minor to have any recognizable effect on the watercourses trenched below the general surface.

Exposures of the material comprising the sand apron are limited, owing to slumping along the valley sides. Where undercutting at the base has freshened the slopes locally, however, it is seen that the material is predominantly fine sand from top to bottom, with some small

lenticular layers of coarser material ranging from grit to coarse angular detritus, suggesting effects of occasional flooding during eolian accumulation. Also some semi-indurated layers of sand suggest buried soils. It is clear that the eolian sand forms a massive wedge in itself, rather than a superficial veneer over alluvial deposits.

The chronology of events indicated by the above relationships is as follows. First there was a sustained interval of eolian sand deposition against the mountainside, from source areas in the desert basin to the west, and interrupted from time to time by flooding from the mountain adjoining at the east. Minor pauses may have permitted a limited degree of soil development. The great bulk of the sand implies that accumulation must have continued over a long span of time. Eventually the influx of new sand came to a halt and wind action lost its effectiveness, owing presumably to changed climatic conditions. The sand surface was stabilized, and flood waters from minor drainage basins within the bedrock areas of the mountain were enabled to begin local removal of the accumulated sand, unopposed by further wind action. This continued without noticeable interruption until the valleys reached their present size. The presence of local sand drifting today suggests the possibility that a reversal may be starting, but this cannot be confirmed within the locality.

The above is by no means a unique occurrence. Similar relations, though on a less striking scale, have been observed on air photos of other areas in the Mojave, and may be seen from some of the main highways in the region.

KELSO DUNE AREA

The location of this area is indicated at B in Fig. 1, and general topography is shown in Fig. 3. The geographic setting is outlined by Sharp (1966). The extent of the dune area is roughly 35 square miles, and local relief is some 500 feet. The main mass of sand is roughly fan shaped, rising to a high ridge at the southeast. Assuming that the underlying surface is of low relief, the volume of sand is estimated to be on the order of 1/2 cubic mile. Accumulation of this amount of sand must have required a long interval of time.

Of particular interest here is the demarcation between active and stabilized sections of the sand surface (Fig. 4B), and stream trenching of the dune area toward the east. The areas of stabilized sand occur primarily on the lower slopes of the dune mass, particularly on the northern and western sides; they make up roughly one third of the total area. From a distance they are conspicuous for their darker color and their sparse cover of shrubs. On air photos their forms are seen to be rounded and subdued, indicating modification by non-eolian processes (Smith, 1940). The expanses of active dune sand are lighter in color, and occur mainly on higher ground. The boundary between them and the stabilized dunes is sharp in some places, gradational in others, and generally convoluted in plan. In the active area, the dominant characteristic is a multiplicity of minor, sharp-crested ridges of complex pattern, in part superimposed on ridges of larger scale, with bare sand drifting freely; details are described by Sharp (1966), who presented results of observations on dune movement over a 15-year interval. He found that although movement was vigorous, it was mostly of a back-and-forth nature, with very little net change

in form or position. He noted also that winds responsible for present activity are of a different orientation than those represented by the stabilized dunes. From these data, together with study of air photos, it is concluded that the active dune forms probably represent relatively recent renewal of movement through rejuvenation of a once entirely stabilized surface, localized by elevation in making for greater exposure to wind and reduced availability of moisture. No influx of new sand is involved, only the reworking of sand already present, and this only in the more vulnerable places. It is most unlikely that the great bulk of the dune sand could have accumulated under existing conditions.

Additional evidence as to the sequence of events is provided by a study of drainage features associated with the dune area. Particularly striking is the course of Cottonwood Wash, shown at the right in Fig. 3. For some 5 miles, the course lies entirely through dune sand, some active and some stabilized; in part, the watercourse marks the boundary between the two. Along much of the course, the valley is narrow, steep-sided, and intrenched 80 to 100 feet below the bordering sand surface. Minor meanders have developed without interference, some minor dunes are definitely truncated by the valley side, and there are no indications of the channel having been blocked by drifting sand; only very locally is there indication of slight channel displacement by sand. It is difficult to picture the watercourse as having survived the main episode of dune building. Rather, it is best explained as postdating that episode, and predating the more recent time of reactivated sand movement.

East of Cottonwood Wash are several other dry washes entering the dune sand area, and supplied by smaller drainage basins. Some die out

in the sand, while a few barely succeed in crossing it. All, however, effect varying degrees of dissection of the tapering, upslope edge of the eolian sand mantle, leaving a ragged margin with several outliers. They are suggestive as to earlier stages in the developmental sequence of Cottonwood Wash itself.

The inferred chronology of local events now may be summarized as follows: (1) building of the dune field from sand sources to the west by vigorous and long-continued action of a wind system different from that of the present, with obliteration or displacement of preexisting drainage lines; (2) climatic change leading to greatly reduced effectiveness of wind action, cutting off of sand supply, and gradual stabilization of the dune surface, permitting gradual extension of drainage lines from upslope areas into and across the dune sand; (3) climatic reversal leading to renewal of wind action in the more susceptible parts of the area, under a wind regime differing from that which originally built the dunes; whether this represents a single episode or a series of minor fluctuations is not clear from information at hand.

CAVE MOUNTAIN LOCALITY

This locality (D in Fig. 1) is on the east-central part of the Cave Mountain topographic sheet. It lies just east of the northeastern tip of Cave Mountain, on a rocky knob some 320 feet high, with its crest at 1440 feet, adjoining Interstate Highway 15 on the south. The features of interest are fossil ventifacts, the largest of which is shown in Fig. 4. These occur in great numbers, and are of coarse-grained crystalline rock. The effects of sandblasting range from smoothing and minor fluting to deep fluting and pitting, with depth of up to 2 inches.

These effects generally are visible only on boulders more than about one foot in height, those smaller being commonly too roughened or crumbled by granular disintegration for retention of surface markings. Weathering of that type is ubiquitous at ground level, and is represented by a mantle of granular detritus; with increasing height, however, its effects are markedly diminished. The marks of eolian abrasion thus are best preserved on the higher parts of the surfaces affected, as in Fig. 4. The question remains, however, as to the relative dates of weathering and of sandblasting. Evidence is found in a comparison of windward and leeward sides of the same boulders at the same hieght. In general, the rock is conspicuously firmer and fresher on the sandblasted side than on the wind-shadow side toward the east. It is inferred that weathering was essentially the same on all sides, prior to sandblasting, and that the latter process removed an appreciable part of the weathered layer on the exposed side, cutting back into fresher rock.

Some weathering, however, has taken place after sandblasting. Even where the abraded surfaces are freshest, a brownish discoloration, suggesting incipient desert varnish, is pronounced, and the contrast with a completely fresh surface is noticeable. Furthermore, the discolored, abraded surface itself has been crumbled locally by granular disintegration. And the abraded surfaces have been interrupted also by cracking and by spalling off of sizeable slabs, probably along partings initiated prior to sandblasting. These effects, although not great, do indicate an appreciable lapse of time since sandblasting ceased.

The absence of eolian sand in the immediate vicinity of the ventifacts provides additional evidence for current inactivity of wind

action. Where eolian sand does occur farther down on the sides of the hill, it is protected by a veneer of granular detritus, and has been gullied by running water. Its emplacement could not have been recent.

Development of the above relationships may be summarized as follows: (1) an interval during which granular disintegration of rock was active, probably under moderately moist conditions; (2) an episode of vigorous sandblasting, with accumulation of eolian sand around the hill, under relatively arid conditions; (3) climatic change which checked sand supply, brought effective wind action to a halt, permitted weathering to continue without interference, and led to mantling and stabilization of nearby sand deposits by detritus carried down by gravity and/or rain wash, accompanied or followed by local gullying of the sand.

CRONESE MOUNTAIN LOCALITY

This locality lies at the northern end of the Cronese Mountains, between East and West Cronese Dry Lakes. It is shown in the east-central part of the Cave Mountain topographic sheet, and is marked C on Fig. 1. The features of special interest are debris-littered slopes of eolian sand on the eastern or leeward side of the mountain. General setting and relations have been described by Evans (1962), whose conclusions are followed except as noted below. The sand is interpreted to have been supplied entirely from the basin west of the mountain, and to have been emplaced by gravity after blowing over the crest of mountain; the term, "falling dune" is applicable. Two sections of the locality may be considered separately, one in which the sand accumulation is comparatively low and broad (Fig. 5A-B), and the other in which it is high and narrow (Fig. 5C). The former section is more northerly, flanks the lower part of the bedrock ridge

continuously for a distance of roughly one half mile, and extends up to a height of several hundred feet; it lies east and north of a sag in the ridge, through which a part of the sand has been blown. From a distance, a marked contrast between darker and lighter parts of the sand accumulation is conspicuous. On closer inspection, it is found that the darker areas are continuously mantled by a detrital layer of angular rock debris (Fig. 5B), a sort of inclined desert pavement which provides protection from eolian attack. The lighter areas, however, are surfaced by freely drifting, normal eolian sand encroaching on the debris-armored surface. This situation was noted in passing by Evans (1962), but not analyzed; he implies, but does not specifically state that the eolian sand was deposited on preexisting talus and fan deposits, filling the voids between loose fragments, but not raising the surface except where blown sand dominates the surface. This interpretation requires some qualification. If the debris-mantled surface itself is considered as a talus, Evan's idea would apply to the modern eolian sand drifting over it. It does not apply, however, to sand beneath the debris mantle, and excavation (Fig. 5B) shows that the debris is a surficial accumulation grading rapidly downward into eolian sand with a sparse admixture of coarser material. It is possible, of course, that this lower and older sand was deposited locally on talus and thins out against talus, but no evidence of this was found, and the absence of true talus on contiguous sand-free stretches of the mountain side casts serious doubt on such an interpretation. It appears rather that eolian sand first accumulated on a bedrock surface, perhaps with a scattering of loose fragmental material, and that the sand later was capped by material having some characteristics of a talus. This material must have been supplied by weathering of ledges

above the sand deposit, moved downward by rolling and sliding, and emplaced at a much more rapid rate than any further increments of eolian sand from the opposite side of the ridge. Since weathering is a rather leisurely process, this implies that influx of eolian sand came virtually to a halt, permitting a stabilized surface to develop. The possibility of occasional minor additions of coarse detritus during the eolian phase of accumulation is not excluded, and the possibility of some flushing of interstitial sand from the coarse detritus by rain wash may be considered, although unproved, but in neither case is the conclusion as to a profound change in relative rates of accumulation of coarser and finer material affected. The fresher eolain sand now in active movement then represents a distinctively new episode, with reactivation of eolian processes long inhibited, and the sand may be regarded as unconformable on the older detrital mantle.

About one mile south of the locality discussed above, an isolated outlier of eolian sand occupies a topographically distinctive position, filling a long narrow ravine extending almost to the mountain top, through a vertical range of some 900 feet (Fig. 5C). From a distance to the east, it has the appearance of a sitting cat in profile. It might be described as a "sand glacier" (Free, 1911, p. 57; Jutson, 1919), and represents a falling dune of unusual size and aspect. Width differs from point to point, and reaches a maximum of roughly 100 feet. The longitudinal profile is rudely convex upward, with a distinct bulge in midsection. The margins are gullied to depths of tens of feet, and sand washed down from the mass has been deposited as an alluvial fan at its base. Gully sides and upper surface alike littered with coarse angular detritus, including some

blocks up to one foot and more in length. Locally along the gullies there is a minor amount of actively drifting sand. On the western side of the ridge crest, the nearest sand is about 600 feet lower and about one third of a mile distant, and is inactive. Evans (1962) attributes this absence of sand on the windward side to depletion of the supply. Obiiously the supply reaching the ridge crest was depleted, but the source area certainly was not exhausted, rather the supply from it was checked by stabilization of the surface and/or diversion to a more northerly direction by a shift in the direction of sand-moving winds, possibly the latter preceding the former.

The inferred sequence of events leading to the above effects was as follows: (1) vigorous drifting of sand from the basin of West Cronese Lake, against and over the northern end of the Cronese Mountains, at some time after desiccation of the pluvial lake which formerly occupied the basin; (2) marked reduction or cessation of sand drifting, followed by gradual mantling of sand slopes by detritus from weathering of exposed bedrock higher up; (3) local gulleying by running water, probably with flushing of residual sand from the upper stretches of valleys on the windward side of the high, narrow sand glacier; (4) reactivation of sand drifting, possibly in a changed direction, and most marked on the west side of the mountain, but with some sand carried over the top.

Reconnaissance observations from the ground and the air indicate that the above relations, with minor variations, are widespread in the mountains east of Soda Lake and in southern Death Valley.

GENERALIZED SEQUENCE OF EVENTS

Although differing somewhat in their individual characteristics, the various localities described above have similar elements of chronology. As considered here, the first major event was an interval of vigorous and prolonged wind action, dominant over other surficial processes, with building of large-scale climbing nes, falling dunes, and other dune fields, local sandblasting of exposed rock surfaces, and probable deflation of basins such as Danby Dry Lake (locality E on Fig. 1). Minor pauses in or interruptions to these processes may have occurred, but left no recognizable morphologic effects. Preceding this episode, conditions had been favorable for granular disintegration and for development of desert varnish in at least some places, although not necessarily concurrently. These weathering processes presumably were interrupted or inhibited by the conditions which promoted wind action.

The above episode of eolian activity was brought to a close by changed climatic conditions which allowed other surficial processes to become relatively more effective. It is not yet clear whether the decline in wind action was partial or complete, local or general, and the possibility remains that in particularly favorable places there was diminuaion rather than cessation. In any event, the work of weathering, gravitational processes, and running water gained greatly in importance, and effects of standing water in basins also may have become significant, although this is yet to be investigated. Sandblasted surfaces on weathered rock underwent spalling and disintegration to varying degrees, and those on fresh rock were stained and discolored. Disintegration of rock ledges in general, perhaps at

an accelerated rate, supplied granular detritus for gravitational movement which, on sand-mantled slopes, led to the accumulation of a distinctive talus-like layer superficially similar to desert pavement. Dune areas were stabilized by vegetation, and underwent gradual smoothing and blurring of form. At some stage, stream dissection of dunes and sand mantles was initiated where catchment areas on rocky surfaces upslope were of sufficient size, and made considerable progress at favorable places. Gradual alteration and effacement of eolian effects were thus the general trend, perhaps with minor and local reversals as yet undetected.

In relatively recent time, at various places, a more definite reversal appears to be in progress, with wind vectors somewhat different from those of the earlier episode, at least locally. This involves mainly a reactivation of sand movement on areas previously stabilized, with little if any addition of new sand from source areas. Mobile dune forms have been reconstituted, and drifting sand has encroached on stabilized surfaces, particularly on leeward slopes. At some places, not described herein, modern sand movement is so vigorous as to have largely obscured the vestiges of any earlier stabilized surface.

TIME OF MAXIMUM WIND ACTION

Within the Mojave, direct evidence for dating the time of maximum wind action is lacking thus far. It is not entirely clear whether the observed effects represent a single episode of eolian activity, or the cumulative effects of more than one episode. Indeed, it is not conclusively established that all of the features referred to were produced at the same time. Comparisons with other areas where

chronological studies are more advanced, however, provide a basis for provisional interpretation.

General evidence as to postglacial climatic fluctuations in western U. S. was summarized by Antevs, a leading investigator, in 1952 and 1955. He recognized a time of maximum aridity, the Altithermal interval, or "Long Drought," dated approximately as from 7500 to 4000 B.P. The succeeding Medithermal interval, extending down to the present, was punctuated by lesser and shorter droughts, of which the most severe was in the latter part of the 13th century (see also Fritts, 1965), and the latest culminated in 1934; intervening times were interpreted to have been as moist or moister than the present.

Antevs' interpretation was questioned later by Martin (1963) on the basis of pollen studies, which failed to reveal evidence of droughts. Martin concluded that the "Altithermal" may have been relatively moist, in summer at least. Malde (1964) pointed out qualifications to Martin's ideas, and concluded that "conspicuous geologic signs characteristic of dry regions are too pervasive and too diverse to be ignored. Our knowledge is incomplete, but my guess is that the Altithermal was first rather arid and then gradually became wetter." Martin and Mehringer (1965) later adopted the agnostic view that "Whatever later discoveries may reveal, there is yet no clear evidence from the floodplain pollen record that suggests 'deserts on the march' or an Altithermal climate in southern Arizona and New Mexico that was appreciably hotter and drier than today's." The concept of an arid Altithermal interval, however, was affirmed by Morrison (1965) on the basis of geological evidence, and by Baumhoff and Heizer (1965) on the basis of archeologic considerations.

More detailed information for a more limited area, the Carson Desert of Nevada, has been provided by Morrison (1964). In Turupah time, correlated with Antevs' Altithermal, maximum aridity was evidenced by complete desiccation of lake basins, and was characterized by intense wind action. Severe deflation lowered basin floors locally as much as 60 feet, and it was estimated that half a cubic mile of sediment was removed from lowlands in the area mapped (about 845 square miles). Sand dunes and eolian sand mantles were developed at lower elevations, and finer material was deposited at higher elevations. This activity came to a close in the Toyeh interval, with soil development and dune stabilization. During ensuing Fallon time, correlated with Antevs' Medithermal, minor fluctuations in lake level were accompanied by relatively minor episodes of renewed eolian activity, involving mostly the reworking of older eolian sands. The recent trend is interpreted to have been toward increasing aridity, increasing windiness, and perhaps greater warmth.

The area described by Morrison is about 150 miles north of that considered here, and is 2000 to 3000 feet higher. Aside from variations related to altitude and latitude, it is in essentially the same climatic zone, and might be expected to have undergone similar climatic fluctuations. It is therefore suggested that the main interval of wind action in the Mojave probably occurred during the Altithermal, with building of the Kelso dunes and other lesser dunes and sand sheets, the deflation responsible for surface lowering in Danby and other dry lakes, and severe sandblasting of bedrock surfaces at various places. Diminution of effective wind action and partial or general stabilization of eolian sands then might be assigned to the transition from the

Altithermal to the Medithermal, with the possibility of local, sporadic renewal of wind action during drier intervals of the Medithermal, perhaps culminating in the present.

CONCLUSIONS

1. Desert conditions are not to be regarded as having been constant in the Mojave during post-pluvial time; there are definite indications of past intervals both more arid and less arid than the present.

2. Current wind action at many places in the Mojave represents a limited recurrence rather than an uninterrupted continutaion of past wind action. The present may be considered as a key to the past only with reservations and qualifications, and present intensity of wind action at a given locale does not necessarily provide an adequate guide for the interpretation of past eolian phenomena.

3. Eolian erosional and depositional features in the Mojave Desert - Death Valley region are best explained as being to a large extent relict in character, dating back to a time of more intense and protracted wind action.

4. Relict eolian phenomena are in accord with the concept of an Altithermal interval characterized by aridity, and may be viewed as giving added support to that concept.

5. Debris-mantled slopes on eolian sand represent a hitherto unrecognized type of geomorphic surface, having significant criterion value for paleoclimatic interpretation.

6. Eolian phenomena in general may provide the best available indicators of past climatic changes in areas where other evidence is lacking.

7. The former greater aridity inferred from eolian phenomena implies past lowering of the water table in desert basins, affecting the various geologic phenomena influenced by the water table. In so far as the water table served as a local baselevel for eolian erosion, for example, a lowering of that baselevel is implied. The earlier interval of aridity inferred by Neal (1965) to account for relict giant desiccation polygons also is in accord with this deduction.

8. In interpreting the stratigraphy of playa deposits, attention should be given to the possibility of erosional unconformities caused by deflation, and of the present playa floor being lower than the original depositional surface.

9. Additional work in geomorphology and related fields is desirable to provide complementary evidence as to the magnitude and duration of the inferred climatic fluctuations, the details of their effects, and the chronology of their succession. It is hoped that this report may stimulate such studies.

10. In photo interpretation studies of other desert regions, attention should be given to the possibility that observed eolian effects may be partly or wholly relict, and to the implications of this for various practical considerations.

REFERENCES

Antevs, E. (1952), Cenozoic climates of the Great Basin: Geol. Rundschau, Bd. 40, p. 94-108.

---------- (1955), Geologic-climatic dating in the West: Amer. Antiquity, vol. 20, p. 317-335.

Barton, D. C. (1916), Notes on the disintegration of granite in Egypt: Jour. Geol., vol. 24, p. 382-393.

Baumhoff, M. A., and Heizer, R. F. (1965), Postglacial climate and archaeology in the desert west: in "The Quaternary of the U. S.," edited by H. E. Wright and D. G. Frey, Princeton University Press, p. 697-707.

Blackwelder, Eliot (1931), The lowering of playas by deflation: Amer. Jour. Sci., vol. 21, p. 140-144.

---------- (1934), Yardangs: Geol. Soc. Amer. Bull., vol. 45, p. 159-166.

---------- (1946), Evolution of desert playas (abst.): Geol. Soc. Amer. Bull., vol. 57, p. 1179.

---------- (1954), Geomorphic processes in the desert: Calif. Div. of Mines, Bull. 170, Chap. V., p. 11-20.

Clements, T., et al (1957), A study of desert surface conditions: U. S. Army Quartermaster Research & Devel. Center, Tech. Rept. EP-53, 111 p. (Natick, Mass.).

---------- (1963), A study of windborne sand and dust in desert areas: U. S. Army Natick Lab., Tech. Rept. ES-8, 61 p. (Natick, Mass.).

Evans, J. R. (1962), Falling and climbing sand dunes in the Cronese ("cat") Mountain area, San Bernardino County, Calif.: Jour. Geol. vol. 70, p. 107-113.

Free, E. E. (1911), The movement of soil material by the wind: U. S. Dept. Agric., Bur. Soils, Bull. 68, p. 57.

Fritts, H. C. (1965), Dendrochronology: In "Quaternary of the U. S.,", edited by H. E. Wright and D. G. Frey, Princeton University Press, p. 871-879.

Groat, C. G. (1967), Geology and hydrology of the Troy Playa area, San Bernardino County, Calif.: Unpublished M. S. Thesis, Univ. of Mass.

Hagar, D. J. (1966), Geomorphology of Coyote valley, San Bernardino County, Calif.: Unpublished Ph. D. thesis, Univ. of Mass.

Jennings, C. W., et al (1962), Geologic Map of California - Trona sheet: Calif. Div. of Mines & Geol.

Jutson, J. T. (1919), The sand ridges, sand plains, and "sand glaciers" at Comet Vale in sub-arid Western Australia: Proc. Royal Soc. Victoria, vol. 31 (new ser.), Pt. 2, p. 412-420.

Kupfer, D. H., and Bassett, A. M. (1954), Reconnaissance geology of the southeastern Mojave Desert, California (abst.): Geol. Soc. Amer. Bull., vol. 65, p. 1275-1276.

------------------------- (1962), Geologic reconnaissance map of part of the southeastern Mojave Desert, California: U. S. Geol. Surv., Min. Inv. Field Stud. Map MF-205.

Long, J. T., and Sharp, R. P. (1964), Barchan-dune movement in Imperial Valley, California: Geol. Soc. Amer. Bull., vol. 75, p. 149-156.

Malde, H. E. (1964), Environment and man in arid America: Science, vol. 145, p. 123-129.

Martin, P. S. (1963), The Last 10,000 Years: Univ. of Arizona Press, 78 p.

---------- and Mehringer, P. J. (1965), Pleistocene pollen analysis and biogeography of the southwest: in "The Quaternary of the U. S.," edited by H. E. Wright and D. G. Frey, Princeton University Press, p. 697-707.

Morrison, R. B. (1964), Lake Lahontan: geology of southern Carson Desert, Nevada: U. S. Geol. Surv. Prof. Paper 401, 156 p.

---------- (1965), Quaternary geology of the Great Basin: in "The Quaternary of the U. S., " edited by H. E. Wright and D. G. Frey, p. 265-285.

Neal, J. T. (1965), Giant desiccation polygons of Great Basin playas: AFCRL Env. Res. Paper No. 123, 30 p.

Norris, R. M. (1966), Barchan dunes of Imperial Valley, California: Jour. Geol., vol. 74, p. 292-306.

Russell, R. J. (1932), Land forms of San Gorgonio Pass, southern California: Univ. of Calif. Publ. in Geog., vol. 6, p. 23-121.

Sharp, R. P. (1963), Wind ripples: Jour. Geol.,vol. 71, p. 617-636.

---------- (1964), Wind-driven sand in Coachella Valley, California: Geol. Soc. Amer. Bull., vol. 75, p. 785-804.

---------- (1966), Kelso dunes, Mojave Desert, California: Geol. Soc. Amer. Bull., vol. 77, p. 1045-1074.

Smith, H. T. U. (1940), Geological studies in southwestern Kansas: Kans. St. Geol. Surv. Bull. 34, p. 159-164.

---------- (1954), Eolian sand on desert mountains (abst.): Geol. Soc. Amer. Bull., vol. 65, p. 1306-1307.

Thompson, D. G. (1929), The Mojave Desert region, California: U. S. Geol. Surv. Water Supp. Paper 578, 759 p.

Wahrhaftig, Clyde (1965) Stepped topography of southern Sierra Nevada, California: Geol. Soc. Amer. Bull., vol. 76, p. 1165-1190.

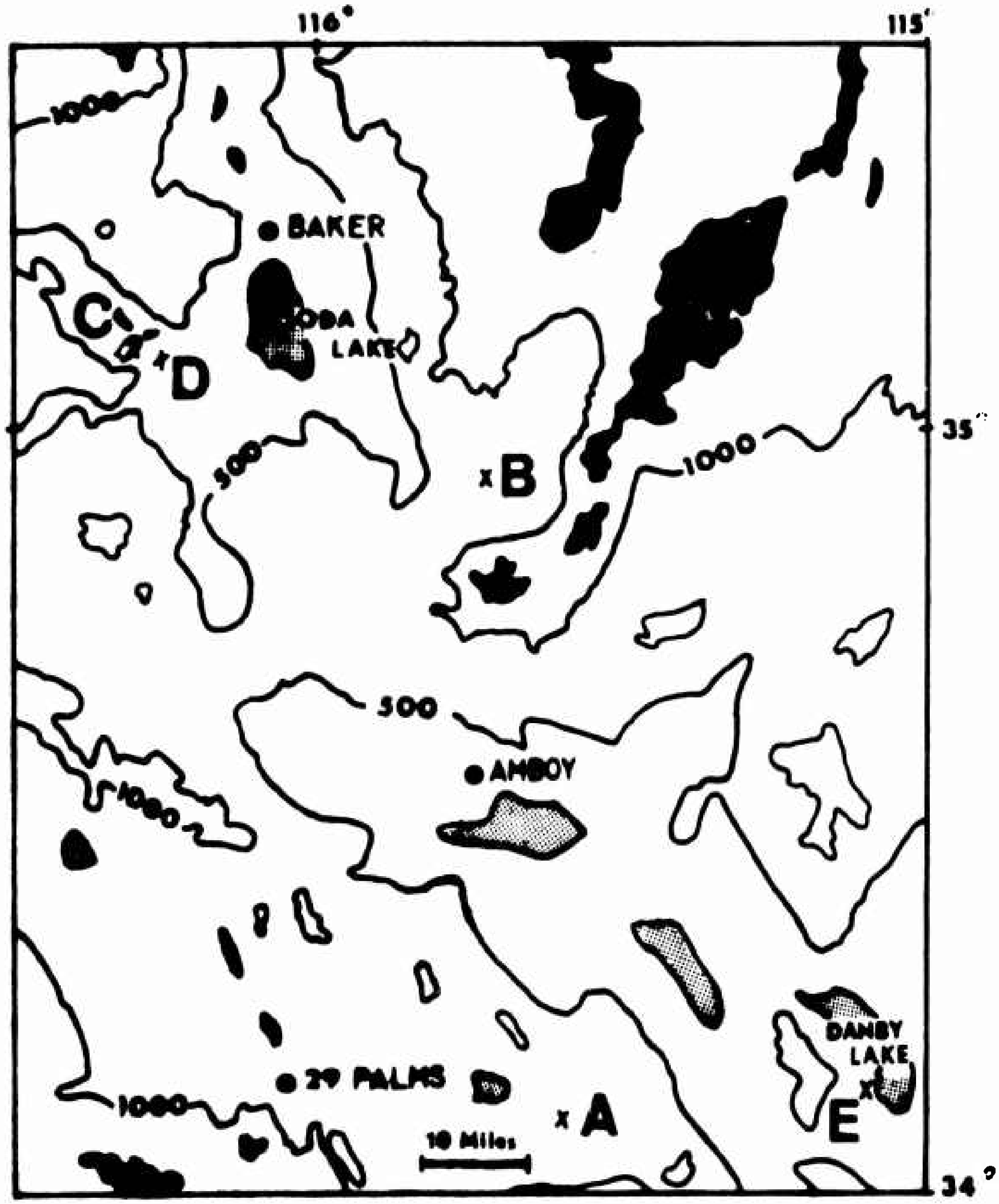

Fig. 1. Sketch map showing location of places discussed in text. Contour interval is 500 meters. Playas are shown by stippling and areas above 1500 meters by solid black.

FIG. 2.

Dissected apron of eolian sand flanking south end of Sheep Hole Mountains on west side, about one mile northwest of Clarks Pass (locality A on Fig. 1; Dale Lake topographic sheet).

A. Looking southwest down the largest of several minor valleys dissecting the sand deposit. Maximum depth is about 130 ft., and width at the bottom approximately 270 ft. A minor fork swings left and follows the contact of sand with bedrock, and the main fork swings right along the same contact, and then continues up a structurally-controlled valley in the bedrock. The sand surface is mostly semi-stabilized.

B. Looking southward at above locality, along dissected contact of sand with bedrock. Note the line of demarcation between lighter rock surface below and darker surface above, which is where the upward projection of the sand surface would have met the mountainside prior to dissection. The difference in color is due to a difference in the proportion of rock surface covered by the varnish.

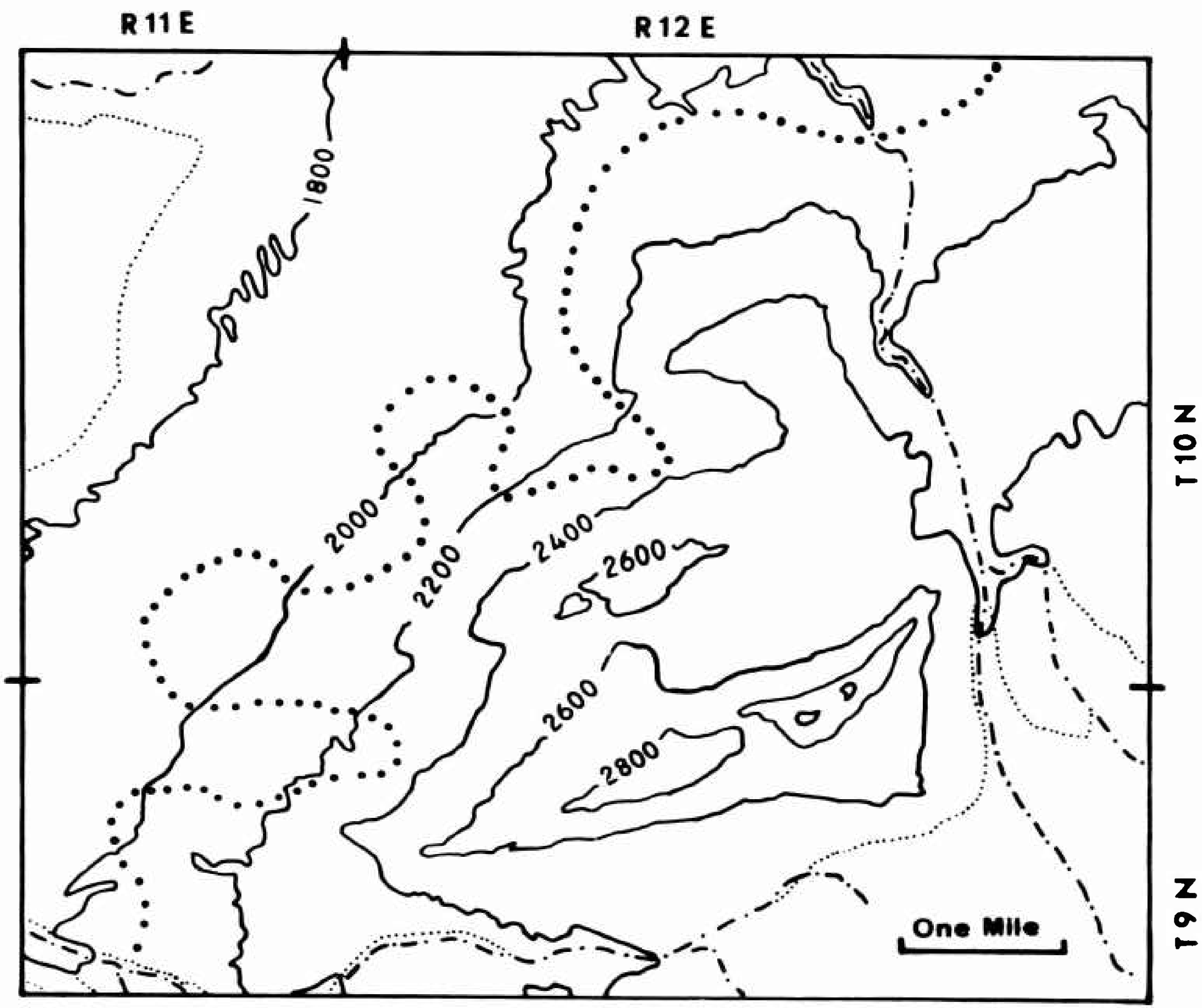

Fig. 3. Generalized contour map of Kelso dune area, on interval of 200 ft., based on Flynn and Kerens topographic sheets. The light dotted line represents boundary of dune area, and heavy dotted line shows boundary between active dune sand (upslope side) and stabilized sand (downslope side). Cottonwood Wash is represented by the dot-and-dash line at the right

FIG. 4.

A. Fossil wind-eroded surface on boulder at top of 320-foot hill east of Cronese Mountains, in SE 1/4 S. 29, T. 12 N., R. 7 E. (locality D on Fig. 1, Cave Mountain topographic sheet). Eolian sand now is entirely absent from the immediate surroundings, in contrast to conditions which must have prevailed when the fluting was produced.

b. View to northeast over western part of Kelso Dune area (locality B on Fig. 1; Kerens topographic sheet; see also Fig. 3). The darker areas with rounded contours represent stabilized dune sand, while the lighter areas with sharp crests mark active dune areas.

FIG. 5.

Accumulations of eolian sand at northern end of Cronese Mountains, on eastern (leeward) side (locality C on Fig. 1; Cave Mountain topographic sheet).

A. Northernmost end of the mountains, in E. 1/2 of S. 13, T. 12 N., R. 6 E., looking northeast. The darker area toward the left represents stabilized, debris-littered sand, and the lighter surface toward the right is of fresh eolian sand actively drifting over the stabilized surface. Sand is blowing over and round the ridge.

B. Closeup view of area in A, above, looking north showing nature of the stabilized surface. Note concentration of rock debris at surface and admixture with eolian sand below; amount of the former decreases rapidly with depth.

C. Sand cascade about one mile south of above locality, looking west, in NW. 1/4 S. 24, T. 12 N., R. 6 E. Note strongly gullied margins. All of the sand surface is debris-mantled except for the lighter strips and patches. The light band at the base is a fan of sand washed down as a result of gullying. Sand drifts are absent from the opposite side of the mountain. Origin of the longitudinal groove is undetermined.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) University of Massachusetts Geology Department Amherst, Massachusetts, 01002	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
PAST VERSUS PRESENT WIND ACTION IN THE MOJAVE DESERT REGION, CALIFORNIA

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Scientific. Interim.

5. AUTHOR(S) (First name, middle initial, last name)
H. T. U. Smith

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December, 1967	25	35

8a. CONTRACT OR GRANT NO. AF 19(628)-2486 b. PROJECT, TASK, AND WORK UNIT NO. 8623-02-01 c. DOD ELEMENT 6144501F d. DOD SUBELEMENT 681309	9a. ORIGINATOR'S REPORT NUMBER(S) Scientific Report No. 1 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFCRL-67-0683

10. DISTRIBUTION STATEMENT
Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Defense, for sale to the general public.

11. SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratories (CRJ) L. G. Hanscom Field Bedford, Massachusetts, 01730

13. ABSTRACT

The major products of wind action in the Mojave - dunes, sand sheets, deflation basins, and deeply abraded rock surfaces - are interpreted to have been formed during a past arid interval followed by an extended time of relative eolian quiescence. Evidence for this is found in: (1) dissection of eolian sand deposits by gullies and stream channels; (2) occurrence of stabilized and modified dune surfaces; (3) accumulations of coarse detrital material mantling depositional slopes on eolian sand; (4) weathering of sand-blasted rock surfaces; and (5) gaps between eolian effects and sources of sand which must have produced them. These indicators occur in different combinations at different places. On the basis of comparison with established chronology in other places, the time of maximum wind action is assigned provisionally to the Altithermal, roughly 7500 to 4000 years ago. Present-day wind action is believed to represent a relatively recent reactivation. These findings have significant implications for playa morphology and stratigraphy.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Altithermal interval						
Climatic change						
Deflation						
Desert pavement						
Desert varnish						
Eolian erosion						
Eolian sand						
Mojave Desert						
Playas						
Sandblasting						
Sand drifting						
Sand dunes						
Wind action						

Unclassified

Security Classification